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MODE-LOCKED FREQUENCY DOUBLED Nd: YAG LASER

FINAL REPORT

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY - EAST

MCDONNELL DOUGLAS CORPORATION

COPY NO. 17

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FINAL REPORT

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PREFACE

This report was prepared by the McDonnell Douglas Astronautics Company - East, McDonnell Douglas Corporation, St. Louis, Missouri, under contract NAS5-20610 Mode Locked Frequency Doubled Nd:YAG Laser. This is the final report of this contract.

The work described herein was carried out by the Advanced Space Avionics Department at the McDonnell Douglas Astronautics Company - East, P.O. Box 516, St. Louis, Missouri 63166.

The project engineer was Dr. J. S. Brookman, Jr. Other contributors to the program were D. D. Meyer, W. E. Heafner and F. J. Richterkessing. The program received technical direction from R. A. Stacy (Branch Manager) in the MDAC-E organization. R. P. Buschard coordinated artwork and report preparation.

MODE LOCKED FREQUENCY DOUBLED LASER

NASA LASER FINAL REPORT

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ABSTRACT

This program included the design, fabrication, test and delivery of two mode-locked, frequency doubled Nd:YAG laser systems. Each system was comprised of two units, the laser head and optics on an Invar plate and the electronics control unit in a relay rack chassis panel. Laser number one operated at a repetition rate of 400 MHz and was designed for use in an optical communication system. Laser number two operated at 200 MHz repetition rate and was designed for optical ranging and target signature experiments. Both lasers had a pulse width of 200 ps at the 10% amplitude points at 1.064 μm wavelength ($\sim$150 ps at 0.532 μm) with an amplitude stability of $\pm$4%. Output power exceeded the design goals.

1. INTRODUCTION

The objective of this program was to design, fabricate, test and deliver two laboratory lasers for use in communications and ranging experiments at the NASA Goddard Space Flight Center. Both lasers were tungsten lamp pumped water cooled Nd:YAG operating at a wavelength of 1.064 μm. Both were acoustooptically mode-locked using a quartz block cut at Brewster's angle to induce proper polarization. A barium sodium niobate (BSN) crystal was used for second harmonic generation external to the laser proper in each case. Table I lists the design parameters of each laser. Each system was composed of two units, the laser head and optics on an invar plate and the electronics control unit in a relay rack chassis panel. Photographs 1 and 2 show the 200 MHz and 400 MHz lasers and control panels.

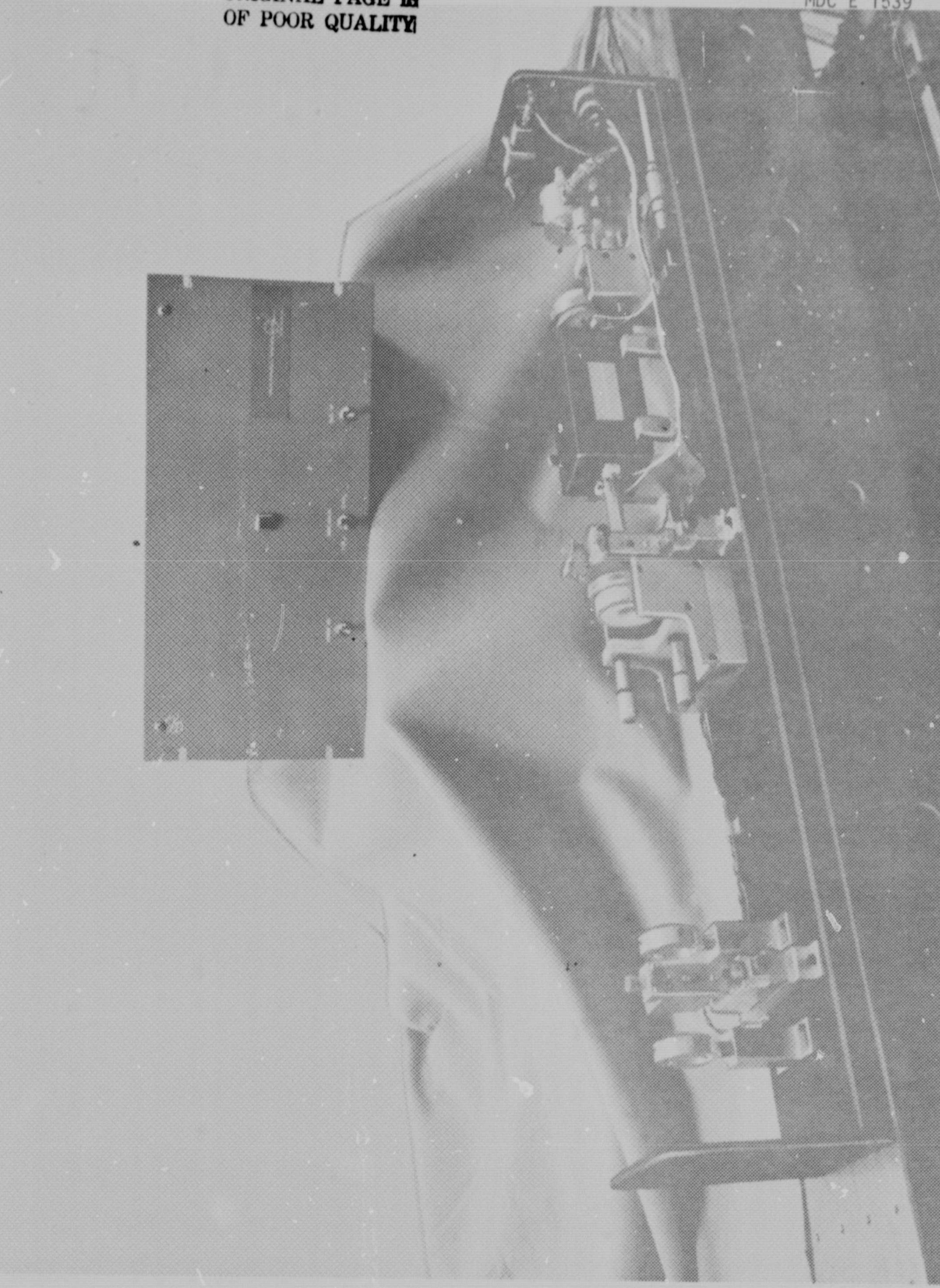
TABLE I SPECIFICATIONS FOR MODE-LOCKED Nd:YAG LASER SOURCE

WAVELENGTH	1.06 μm	0.53 μm
OUTPUT POWER	100 mW	≥ 1 mW ①
OUTPUT AMPLITUDE STABILITY	< ± 5%	< ± 10%
MODE STRUCTURE	TEM_{00}	TEM_{00}
MODE-LOCKED PULSE REPETITION	400 MHz ②	400 MHz ②
MODE-LOCKED PULSE WIDTH (AT 10% POINTS)	≤ 200 ps	≤ 160 ps
MODE-LOCKED HOLD TIME	≥ 8 HR	≥ 8 HR
OUTPUT BEAM DIAMETER	~ 1.0 mm	~ 1.0 mm
OUTPUT BEAM DIVERGENCE	2.5 mrad	1.25 mrad
OUTPUT BEAM ELLIPTICITY	BETTER THAN 11:10	BETTER THAN 11:10
POLARIZATION DIRECTION	VERTICAL	HORIZONTAL
POLARIZATION PURITY	≥ 50:1	≥ 50:1
COOLANT TEMPERATURE/FLOW RATE	50 ± 4°F/1 gpm	50 ± 4°F/1 gpm
LAMP POWER REQUIREMENTS (MAX)	15A AT 120V	15A AT 120V
RF FREQUENCY (AOML)	200 MHz ③	200 MHz ③
RF POWER (AOML)	1W	1W

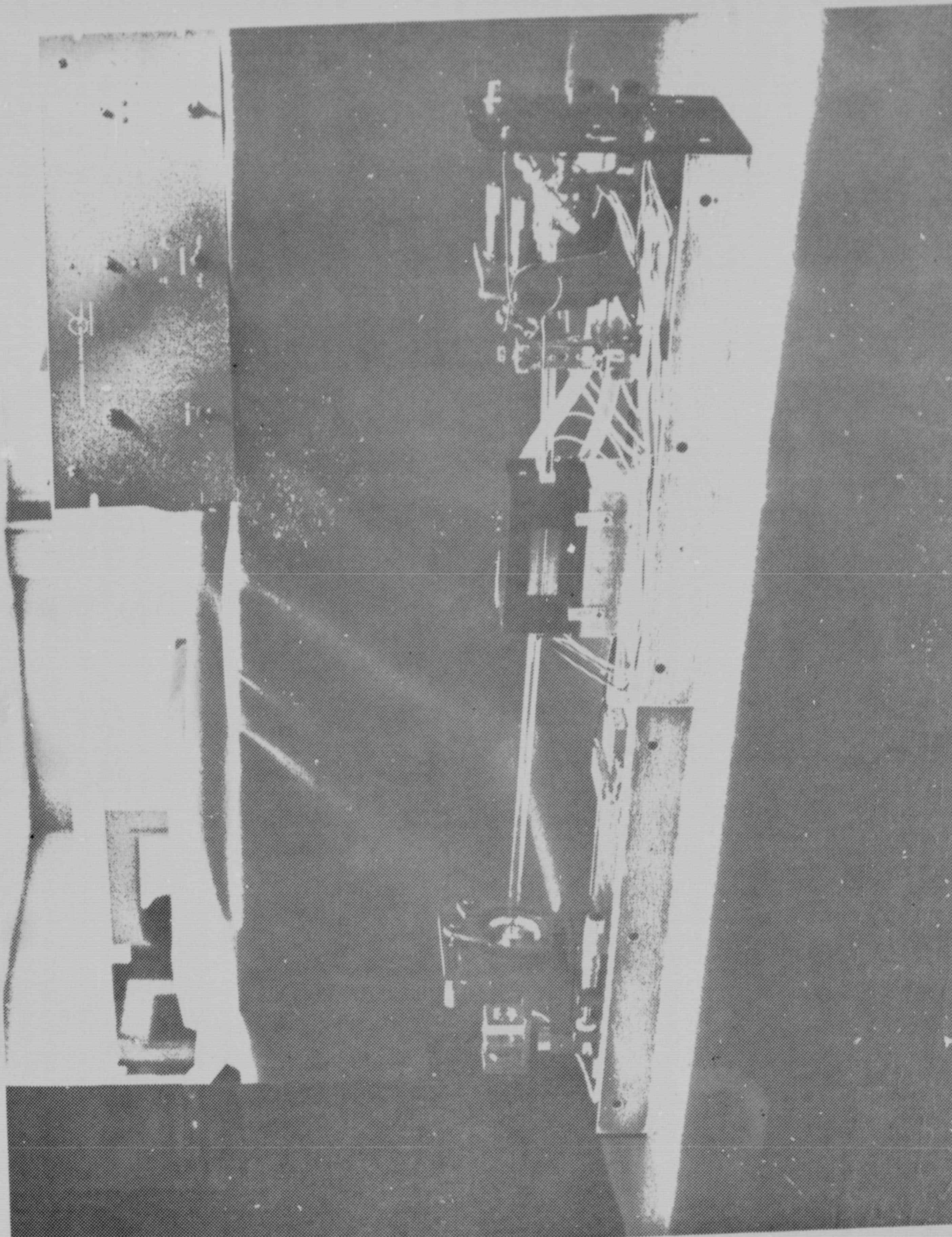
① ≥ 1.5 mW FOR SECOND LABORATORY LASER

② 200 MHz FOR SECOND LABORATORY LASER

③ 100 MHz FOR SECOND LABORATORY LASER



PHOTOGRAPH NO. 1 400 MHz LASER AND CONTROL PANEL



PHOTOGRAPH NO. 2 200 MHz LASER AND CONTROL PANEL

2. DESIGN

Since both laboratory lasers have many common components, this section will concentrate on lab laser number one (400 Mpps) followed by a discussion of the design differences used for lab laser number two (200 Mpps). Figure 1 is a block diagram of the laser system. The laser head assembly outline drawing is shown in Figure 2 with the dust cover removed. The resonator design was based on an approach that had been proven to give stable consistent performance in other MDAC-E laboratory laser designs. It used the minimum number of intracavity elements to reduce static losses. The mode-locker crystal was cut at Brewster's angle, thus serving to polarize the laser output as well as not requiring an anti-reflection coating. The laser rod faces were cut and polished with a 1° tilt from the normal to the optical axis to eliminate any intracavity etalon effects that would narrow the oscillating bandwidth, thus increasing output pulse width. For the same reason, the output coupling mirror also had a 1° wedge. Past experience with these components had shown that the optimum output power and stability was obtained when the transmission of the output mirror was 2.0% $\pm$0.25%. The radius of curvature of the highly reflecting mirror was chosen empirically based on cavity length, thermal lensing of the laser rod, desired spot size in the mode-locker, and desired degree of mode fill in the laser rod. The spot size at each mirror, power output, pulse width, and general feel of adjustability were recorded for a variety of HR mirrors from the shortest that would permit lasing ($\sim$30 cm) to the longest that would still not create too large a spot in the mode-locker for the 1.0mm acoustic column ($\sim$2.5m), and the one that best fit the requirements selected.

2.1 <u>Pump Cavity</u> - The pump cavity was a commercial water cooled double ellipse configuration manufactured by GTE Sylvania (Model 610). The 3mm diameter by 75mm long Nd:YAG rod was mounted at the common focus of the two elliptical cavities. A 1000 watt tungsten iodine lamp (General Electric number Q1000T3/4CL or ANSI code FCM) was mounted at each of the other focii of the double ellipse. The reflective surfaces of the inside walls of the pump cavity were high polish gold coated. Cooling water was first passed over the laser rod, then through the top half of the pump cavity and exited from the lower half. The most quiet operation of the laser was obtained at about 1.4 gallons per minute flow rate. An absolute minimum flow rate of 1.0 gallon per minute was required to remove the heat generated by the pump lamps. A flow rate of greater than 1.75 gallons

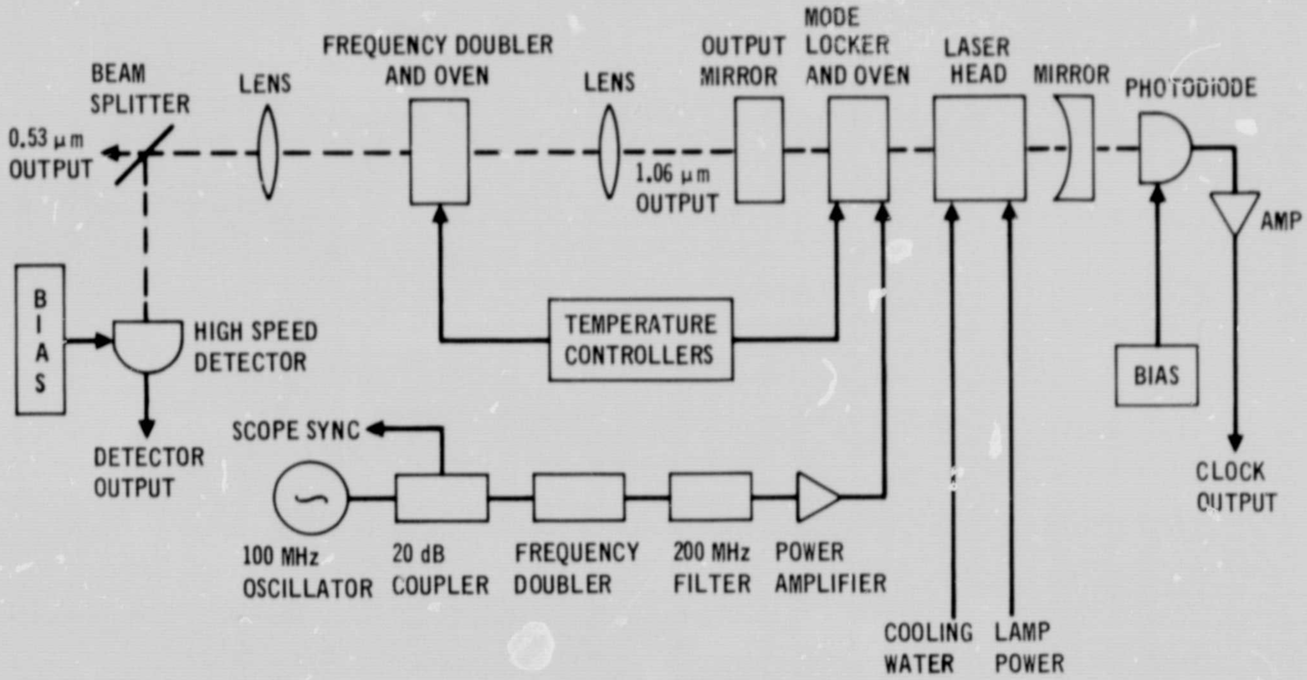
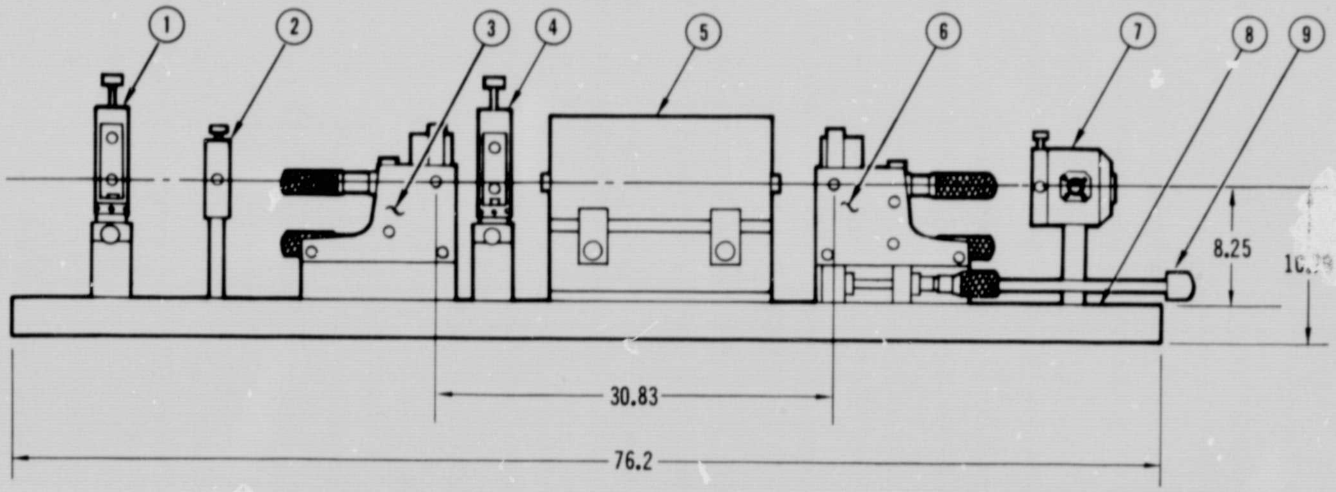


FIGURE 1 400 MHz MODE LOCKED FREQUENCY DOUBLED Nd: YAG LASER BLOCK DIAGRAM



1 – FREQUENCY DOUBLER & MOUNT
2 – CONVERGING LENS & MOUNT
3 – RESONATOR MIRROR M_2 & MOUNT
4 – AOML AND MOUNT
5 – PUMP CAVITY
6 – RESONATOR MIRROR M_1 & MOUNT
7 – CLOCK DETECTOR
8 – INVAR BASEPLATE
9 – RESONATOR SPACING ADJUSTING KNOB

FIGURE 2 LASER ASSEMBLY OUTLINE DRAWING

per minute resulted in excessive internal pressure and could produce internal leaks at either the cavity or rod holder sealing rings. The cooling water return line must be of sufficient size to eliminate excessive back pressure or again leaks could develop. A minimum size of 9.5 mm (3/8 inch) inside diameter is recommended.

The pump lamps must be clean when installed or rapid deterioration will result. It is also desirable to clean the contacting electrodes since any resistance at these points will result in excessive temperature at the glass to metal seal of the lamp. Some cooling of the lamp ends is obtained by heat transfer from the lamp to the electrical wire. For this reason the springs used to establish good electrical contact were replaced with stronger units than those delivered with the pump cavity. A maximum of 7 pounds of pressure is recommended by the lamp manufacturer.

In operation, the temperature of the entire pump cavity was reduced below that of the surrounding laboratory by the chilled water. To reduce the thermal load on the water cooling system, the pump cavity was semi-insulated from the baseplate by a thin wall spacing block that also determined the optical center line height above the baseplate.

2.2 <u>Acoustooptic Mode-Locker (AOML)</u> - The acoustiooptic mode-locker used in the lab lasers was fabricated at McDonnell Douglas Astronautics Company - East. A lithium niobate transducer was vacuum thermal compression bonded to a quartz block having Brewster angle faces on the optical axis. The thickness of the transducer was reduced by standard grinding and polishing methods on a flat lap until the primary resonant frequency was in the desired range of operation. A 1.0mm electrode was then vacuum deposited on the transducer and the entire assembly was mounted in a copper heat sink along with a heater element. A thermistor, located inside the upper heat sink was used for feedback to the temperature controller for the heater. A thermocouple was also mounted on the heat sink and its leads brought out for external monitoring of crystal temperature. Electrical connection was made to the transducer by means of a coaxial cable that was routed through a hole in the copper heat sink cylinder. This design minimized heat gradients and heat losses due to the coaxial cable. For efficient operation, it was necessary to provide an impedance matching network between the transducer and the RF power amplifier.

Figure 3a is a network analyzer display of the impedance of the transducer and quartz block only, over a 600 kHz range centered near 200 MHz. The display is normalized to 50Ω and shows that, at resonance, an apparently excellent match is obtained. Experience has shown that this is not a stable operating point when RF input power is in the one watt or greater range.

The acoustic resonant frequency of the quartz block used in the mode-locker is a function of the velocity of sound in the medium and the physical thickness of the block. For a 5mm thick quartz block, these resonances occur approximately every 600 kHz. Both the velocity of sound and the thickness are functions of the temperature of the block. The net effect of these two perturbations is to increase the resonant frequency as temperature is increased. This effect is clearly seen in Figures 3b and 3c.

In Figure 3b the synthesizer is sweeping from 199.5 MHz to 200.5 MHz in a period of one second (1.0 MHz/s or 0.1 s/div). The upper trace is the voltage reflected from the device under test and is three divisions full scale. Thus an open or short circuit load would be represented by the top graticule line and a 50Ω load would be represented by the center graticule line. The lower trace is diffracted optical power in arbitrary units with zero being the lower graticule line. As can be seen, peak diffracted, power occurs when the device passes through a body resonance and the impedance is 50Ω. The 600 KHz spacing of body resonances is also shown since the sweep rate is 100 kHz/division. The "dotted" effect is due to digital stepping of frequency.

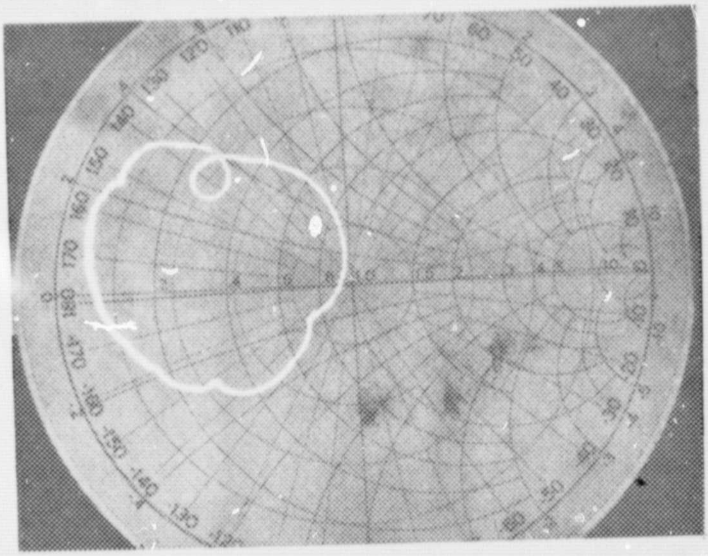
Figure 3c is identical to Figure 3b except that the sweep rate has been reduced by a factor of ten (100 kHz/s or 1 s/div). The effects of absorbed RF power in heating the mode-locker are seen to be significant in periods as short as three seconds, compared to Figure 3b where the process is isothermal. Notice that on the fourth horizontal division, when the drive frequency gets to be slightly higher than the body's resonant frequency, resulting in less power being absorbed, there is a "snap-over" action as the mode-locker cools off resulting in a lower frequency body resonance.

Figures 4a, b, and c are identical to Figures 3a, b, and c except that the matching network has been added. The same scale factors were used as in Figure 3. Notice that the diffracted light power does not go to zero amplitude now when off resonance as it did without the matching network. The slow sweep (Figure 4c) shows that the self-heating effects have been reduced considerably since a more nearly even level of RF power is being absorbed as a function of frequency. The input power was set to 1.0 watt at 200 MHz and the power in both the diffracted beam and the power in the undiffracted beam was measured using a linear power meter at 1.064 μm input wavelength. The ratio of these two powers gives the diffraction efficiency, in this case we have 7%/watt, time averaged for CW input. Operation at this point was very stable. Interruption of the RF drive power for up to 15 seconds did not change the operating point. Recovery to this point took about four seconds. Without the matching network it was impossible to keep the device at the point of peak diffraction efficiency.

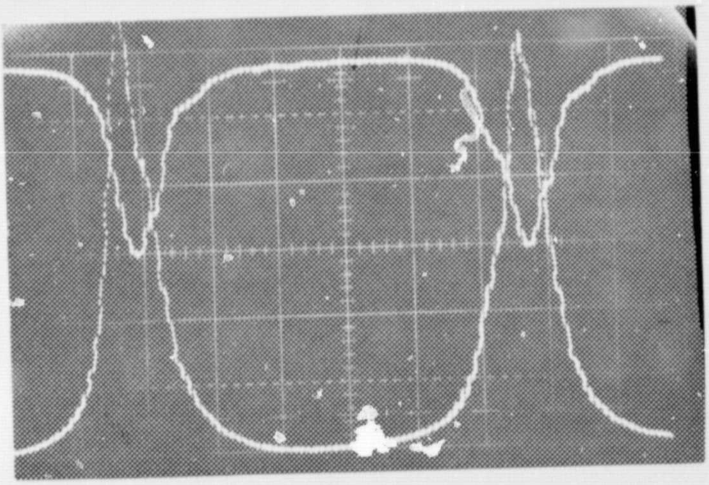
The mode-locker and heater assembly were mounted in a 4 axis positioning device that permitted the proper adjustment of height, Brewster angle, Bragg angle, and transverse centering in the optical beam. All adjustments were provided with locking devices.

2.3 Mirror Mounts and Translation Stage - Standard commercial mirror mounts were used. When adjusted to the proper operating point, it is desirable to secure the locking device to prevent accidental misalignment. The translation stage used to adjust cavity length uses a differential micrometer to obtain finer control than was possible with the ordinary micrometer normally supplied. If there is not sufficient range of travel to obtain peak performance, it will be necessary to recalibrate the length adjustment. Set the micrometer to the center of its range, loosen the set screw holding the micrometer on the dove-tailed slide and manually position cavity length for best results. Tighten the set screw and make fine adjustments with the micrometer.

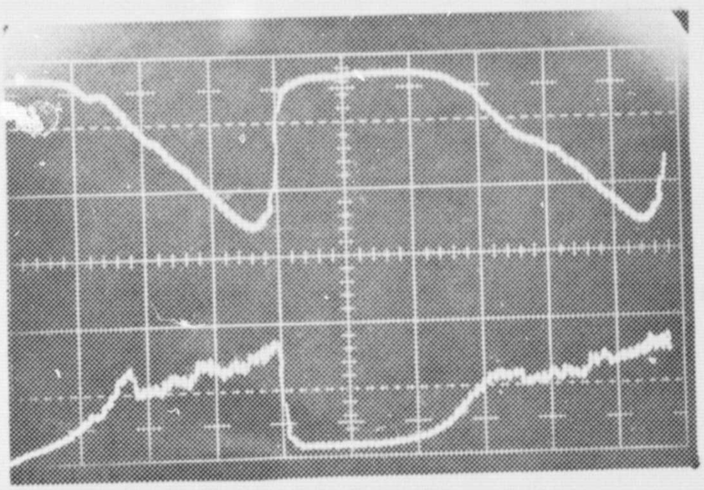
2.4 Second Harmonic Generator (SHG) - The second harmonic generator used the same heater core and mechanical positioning devices as the mode-locker. The



a IMPEDANCE REFERENCED TO 50Ω

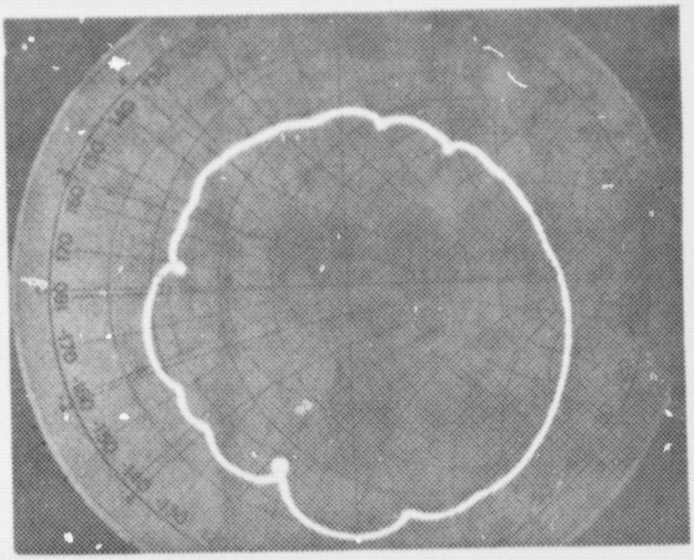


b VSWR AND DIFFRACTED POWER FAST (ISOTHERMAL) SWEEP (SEE TEXT FOR SCALE FACTORS)

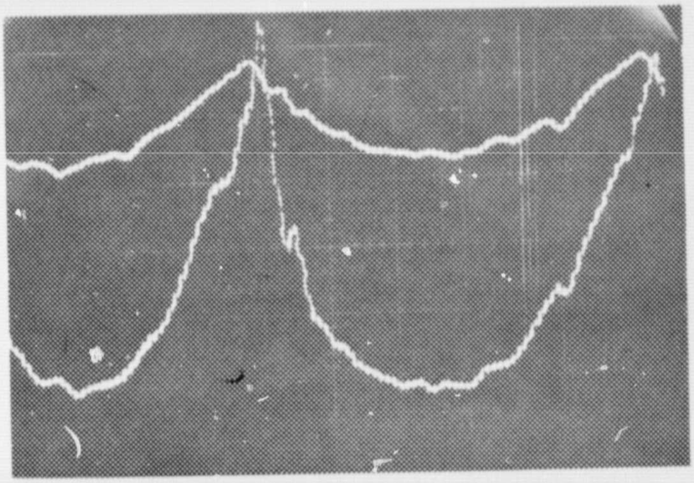


c VSWR AND DIFFRACTED POWER SLOW SWEEP RATE (SEE TEXT FOR SCALE FACTORS)

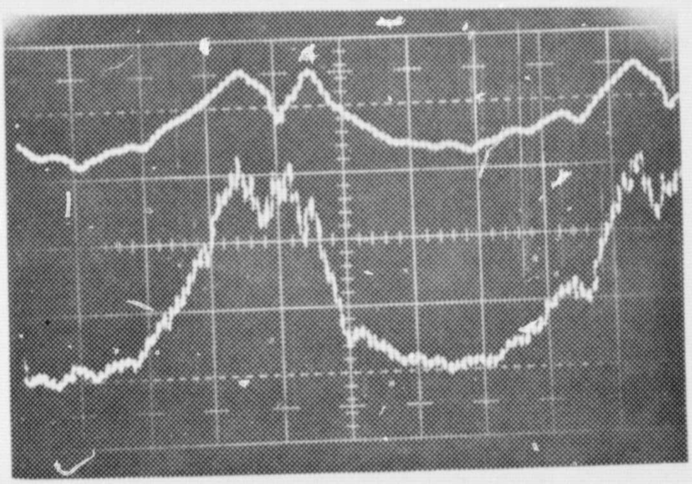
FIGURE 3 MODE-LOCKER PERFORMANCE WITHOUT MATCHING NETWORK



a IMPEDANCE REFERENCED TO 50Ω



b VSWR AND DIFFRACTED POWER FAST (ISOTHERMAL) SWEEP (SEE TEXT FOR SCALE FACTORS)



c VSWR AND DIFFRACTED POWER SLOW SWEEP RATE (SEE TEXT FOR SCALE FACTORS)

FIGURE 4 MODE-LOCKER PERFORMANCE WITH MATCHING NETWORK

crystal was barium sodium niobate and was temperature tuned to the optimum phase matching condition. Two lenses of 25mm focal length were used to increase the power density inside the crystal and then recollimate the output radiation. Focusing and positioning adjustments were provided on each lens.

2.5 Baseplate - To achieve both mechanical and thermal stability, all components of the laser head were mounted on a 25mm (1 inch) thick Invar baseplate.

2.6 System Clock - A Texas Instruments TIXL-56 photodiode was used in a mounting system developed by MDAC-E. This diode was operated in a constant current mode to reduce phase shift of the output signal as a function of input amplitude. The output of the photodiode was amplified to a useful level (0 dbm) and brought out through the laser head rear panel on an OSM connector. Figure 5 shows the system clock schematic.

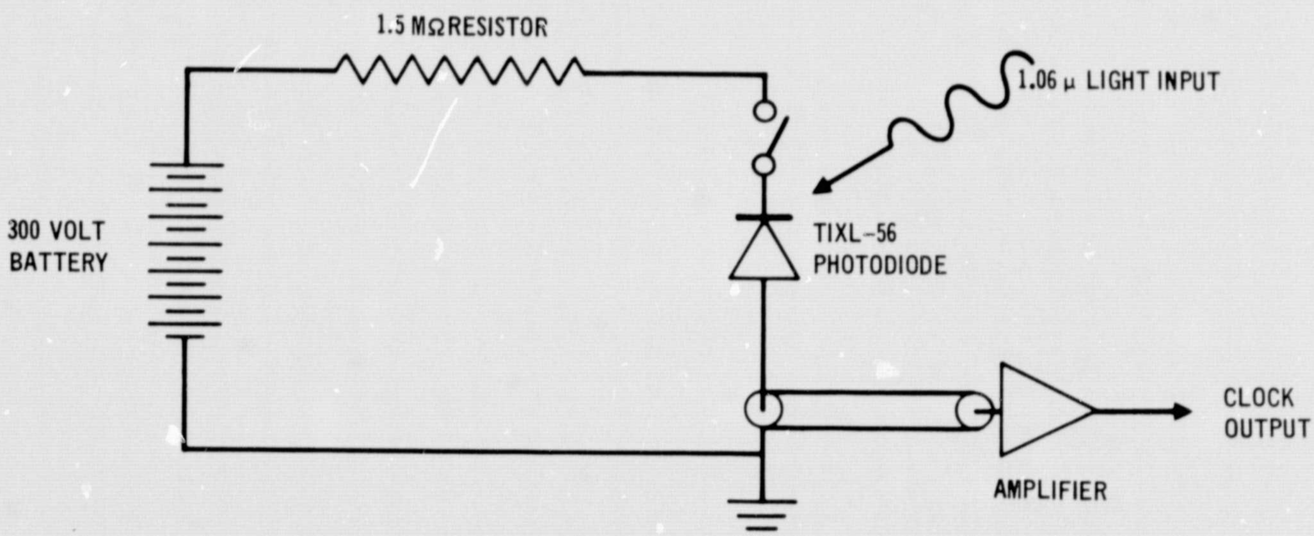


FIGURE 5 SYSTEM CLOCK SCHEMATIC

2.7 Mode-Locker R.F. Drive - The mode-locker RF drive train consists entirely of commercial units assembled on a relay rack mounted chassis. The basic oscillator is a 100.00 MHz CTS Knight temperature compensated crystal oscillator (TXCO) followed by a 20 dB directional coupler (MERRIMAC) that provides a sample of the RF drive for scope triggering. This is followed by a frequency doubler (Werlatone FD 10) and filter (Teleonic) to give a clean 200 MHz input signal for the power amplifier (RF Power Labs model FK250-2M). An adjustable attenuator on the input of the power amplifier permits setting the output power level for optimum operation of the mode-locker.

2.8 Temperature Controllers - Figure 6 includes the block diagram of the temperature controller. The circuit consists of the sensor bridge, temperature compensated high gain amplifier, oscillator, integrator, comparator, and output buffer amplifier. The temperature sensing thermistor located in the second harmonic generator assembly was connected to one leg of a bridge, and precision resistors were used in the other legs. The thermistor in the bridge had a temperature coefficient of approximately 1% per degree centigrade, and had a nominal impedance of 1000 ohms at 88°C. The resistors were selected so that the bridge output was nulled at the desired operating temperature.

The heater in this system was switched completely on or off at any given time, with the amount of heating being controlled by the on-to-off ratio of the heater. The oscillator developed a rectangular waveform which was integrated to produce a triangular waveform with zero average value. This triangular waveform was the reference voltage for a high gain comparator. The other input to the comparator was the amplified error signal from the thermistor bridge. The output buffer amplifier controlled the power supplied to the heater in the oven.

A second temperature controller, located in the same chassis was used to keep the mode-locker tuned to an acoustic body resonance at approximately 48°C. Electrical waveforms of both sections of the dual temperature controller are included.

2.9 Power Supplies - Commercial power supplies were used to provide the necessary input power to the components. The +24 Vdc is provided by a LAMBDA model LCS-C-24 mounted on the relay rack chassis. The +15 Vdc and -15 Vdc were obtained

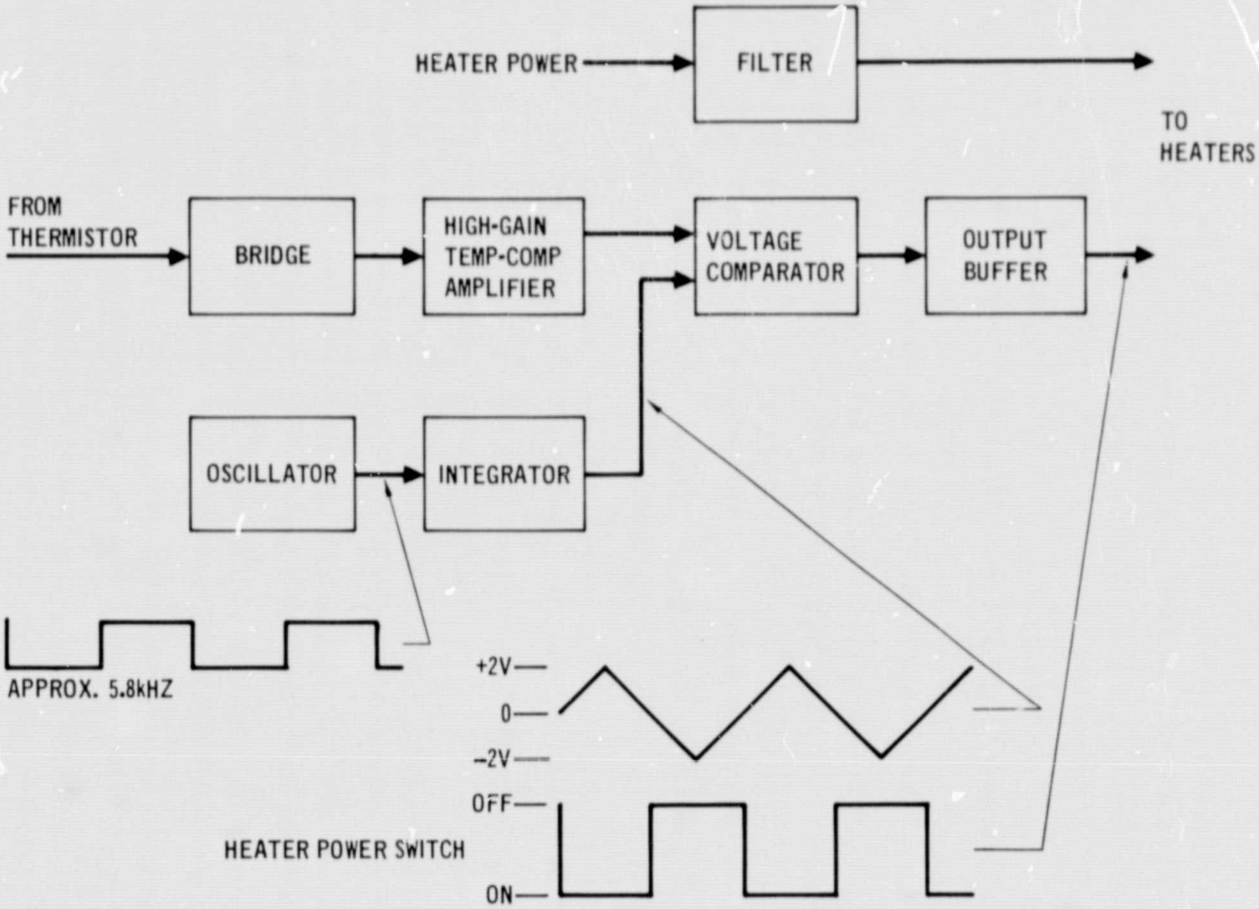


FIGURE 6 TEMPERATURE CONTROLLER BLOCK DIAGRAM

from a POWERTEC model 2L15D-2.8 mounted on the opposite side of the relay rack chassis.

2.10 <u>200 Mpps Laser</u> - The design of the 200 Mpps laser closely followed the proven design of the 400 Mpps laser but with one significant change in the resonator configuration. A repetition rate of 200 Mpps requires an optical cavity length double that of the 400 Mpps laser. In the past, it was typical practice to form the beam waist at the output coupling mirror, then using a suitable lens to form a demagnified image of this waist inside the frequency doubling crystal as shown in Figure 7.

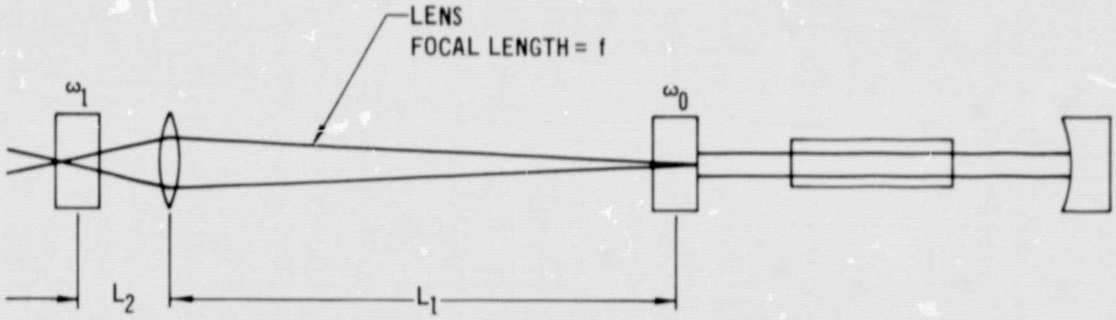


FIGURE 7 TYPICAL LASER AND FREQUENCY DOUBLING CRYSTAL SCHEMATIC DIAGRAM

Spacing of the elements is determined by the condition

$$\frac{1}{L_1} + \frac{1}{L_2} = \frac{1}{f}$$

and spot size in the crystal is determined by

$$\omega_1 = \frac{\omega_o L_2}{L_1}$$

ω_o is fixed by the resonator parameter and is typically of the order of 1mm diameter. To obtain a small spot size in the crystal for efficient doubling it is necessary to use a short focal length lens and to locate it a considerable distance from the flat mirror. Typical figures are f = 12.5mm $L_1 \sim 75$ cm.

The design schematic used in the 200 Mpps laser is shown in Figure 8.

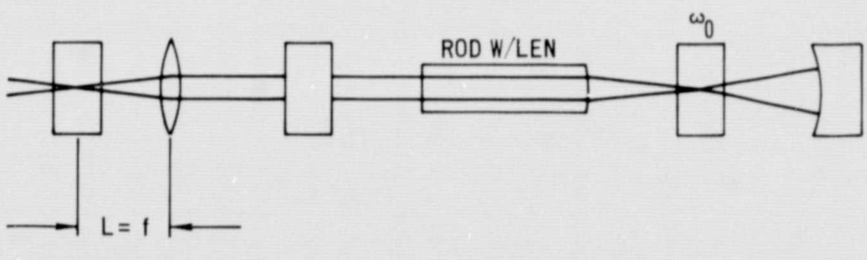


FIGURE 8 200 Mpps LASER DESIGN SCHEMATIC DIAGRAM

The beam waist ω_0 is formed inside the mode locker by the convex surface formed at one end of the laser rod. This results in a collimated beam through the laser rod and a diffraction limited spot size in the crystal when L = f, the focal length of the lens.

The optimum radii of curvatures and spacing of optical elements was determined using a computer program developed at MDAC-E to give the best mode volume in the laser rod. This restricts the laser to TEM_{00} mode operation when properly adjusted and utilizes the maximum volume of active material for peak output power. The same effect could be achieved with a laser rod with flat ends and an intracavity lens of proper focal length but this would result in two extra air-glass interfaces with their attendant scattering and reflection losses. This is the first known use of integrating the laser rod and intracavity lens. Greater than fourfold average output power was realized by this design compared to the 400 Mpps laser discussed earlier in this report. No problems in pulse width or amplitude stability were encountered and spacing of elements was found to be insensitive to $\pm$3mm variation from theoretical.

3. SYSTEM TESTS AND RESULTS

Upon completion, each laser was subjected to a series of tests to verify compliance with the design specifications. The following sections describe the method of measurement and results for each test performed on each laser.

3.1 Output Power - Optical output power of both lasers at 1.06 μm was measured using a Coherent Radiation model 210 optical power meter. This meter utilizes the heating effect of incident radiation on a series of thermopiles, making its response independent of wavelength. Intercomparison at NASA GSFC with their thermopile meter showed agreement between the two meters to 5% at several different power levels.

Output power was measured in normal mode-locked running configuration, after the lasers had operated for one hour with an input voltage of 90V $\pm$1V to the pump lamps. The average power, not the mode-locked peak power, was recorded. Laboratory laser number one (400 Mpps) was specified for an output power of 100 mW, actual output power was 150 mW. Laboratory laser number two (200 Mpps) was specified for 100 mW also, actual output power was greater than 750 mW.

Optical output power at 0.53 μm wavelength from laboratory laser number one (400 Mpps) was measured with an EG&G model 575 radiometer, rather than using the thermopile meter, due to the low power. The design goal was 1 mW, with 1.5 mW achieved.

The design goal for the 200 Mpps laser was greater than 1.5mW. The thermopile power meter was used and the output power measured greater than 20 mW.

3.2 <u>Pulse Width</u> - Mode-locked pulse width was measured at the 10% of peak amplitude points using an MDAC-E high speed photodiode with a risetime of less than 70 pps into a Tektronix S-4 or S-C sampling head with risetimes of 25-30ps. The specification of 200 ps at 1.06 μm was met by both lasers. A typical output is shown in Figure 9.

200 ps
PER DIVISION

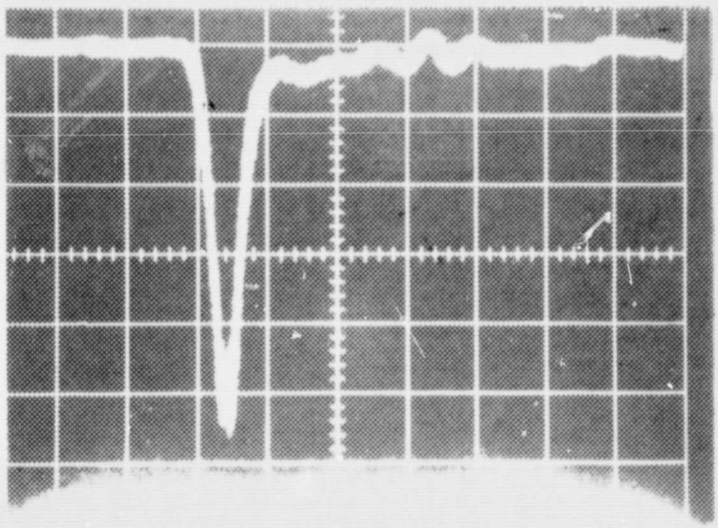


FIGURE 9 SCOPE PHOTO OF SINGLE PULSE

3.3 <u>Amplitude Stability</u> - The amplitude stability of each laser was measured by intercepting a portion of the output beam with a silicon photodiode power meter. The analog output signal of the silicon photodiode power meter (Coherent Optics model 900) was recorded on a Sanborn strip chart recorder. Both lasers met or exceeded the ±5% amplitude stability criteria at 1.06 μm wavelength as shown in Figures 10 and 11.

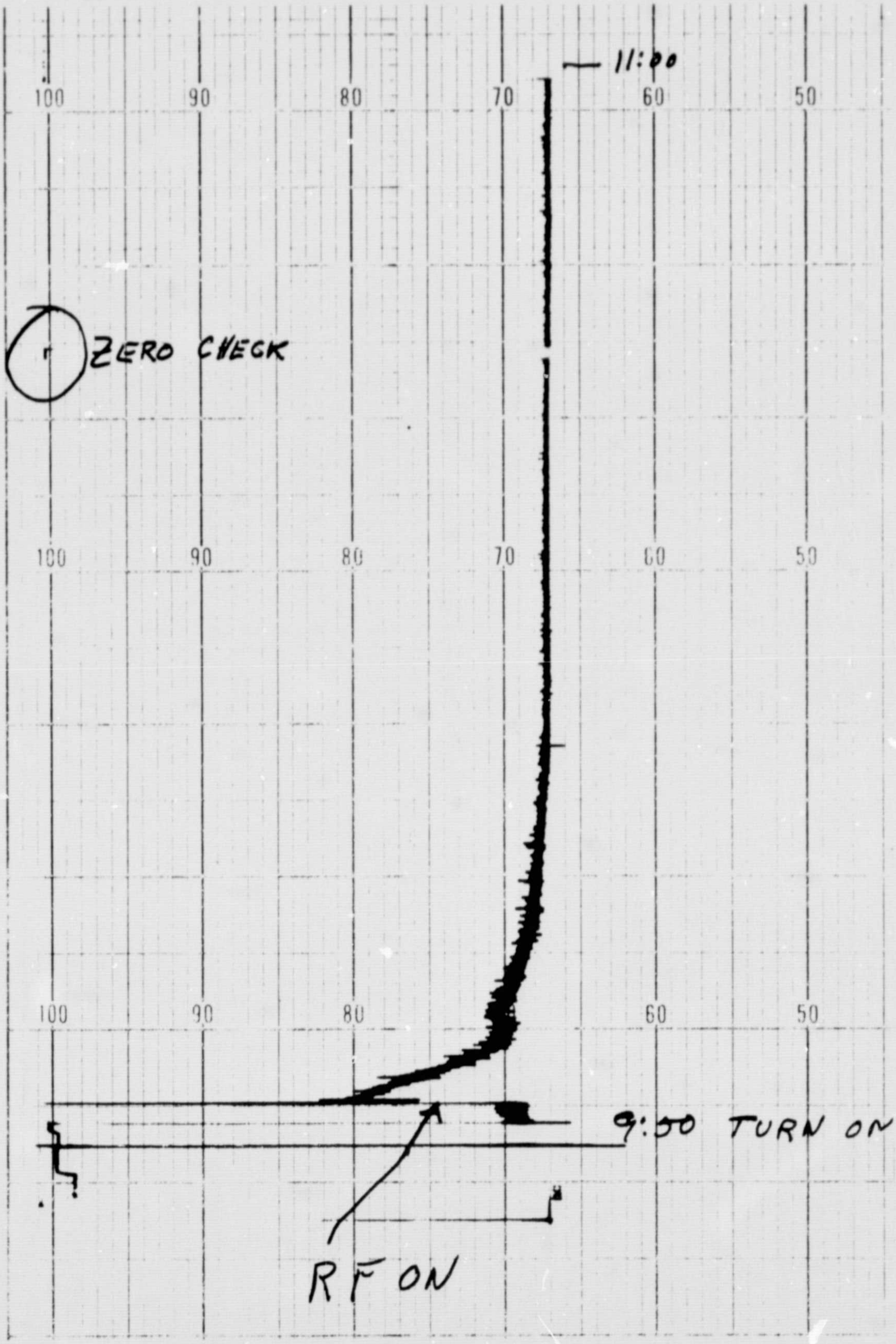


FIGURE 10 AMPLITUDE STABILITY FROM START UP
200 MHz Laser

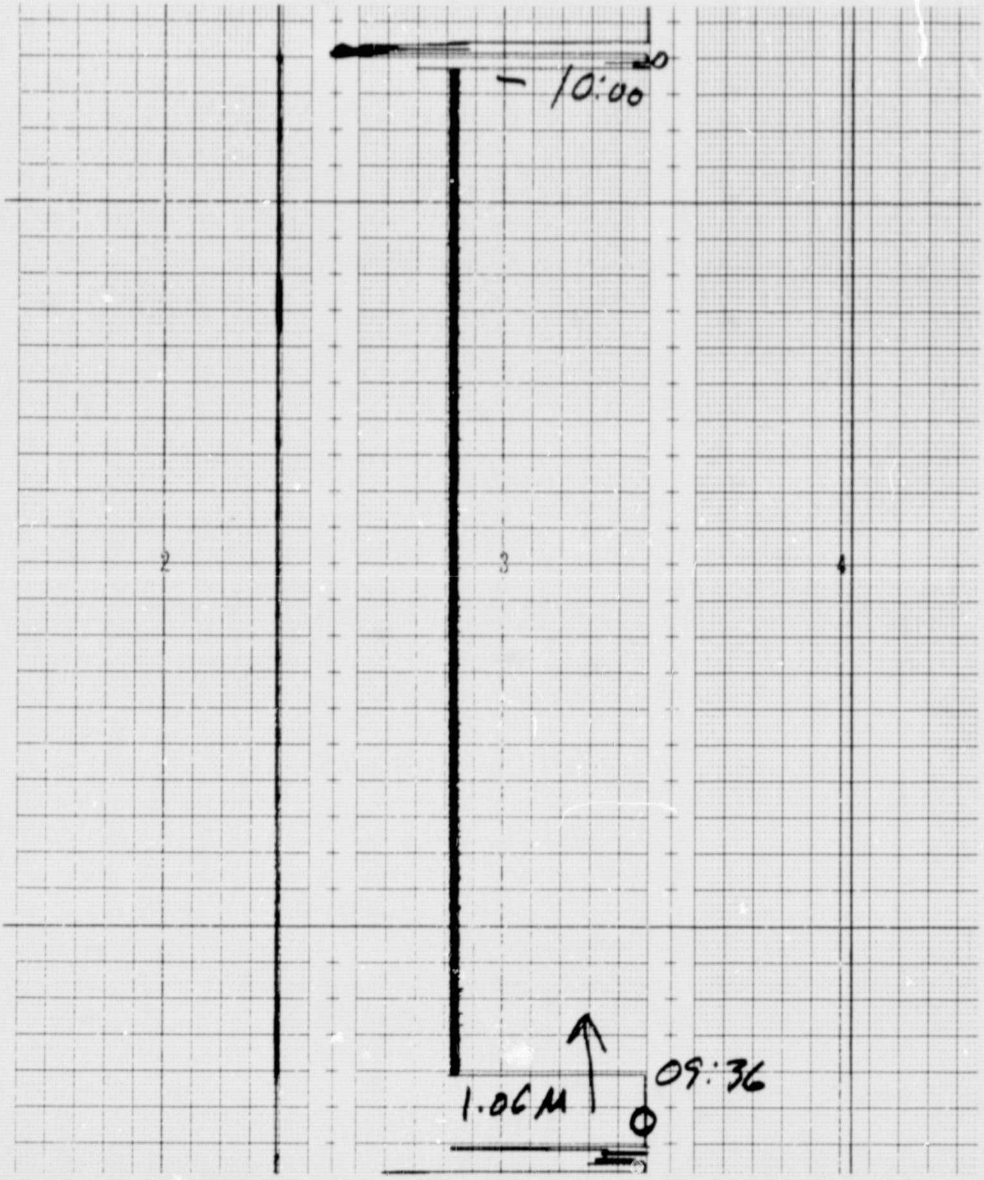


FIGURE 11 1.06μ AMPLITUDE STABILITY AFTER WARMUP PERIOD
200 MHz Laser

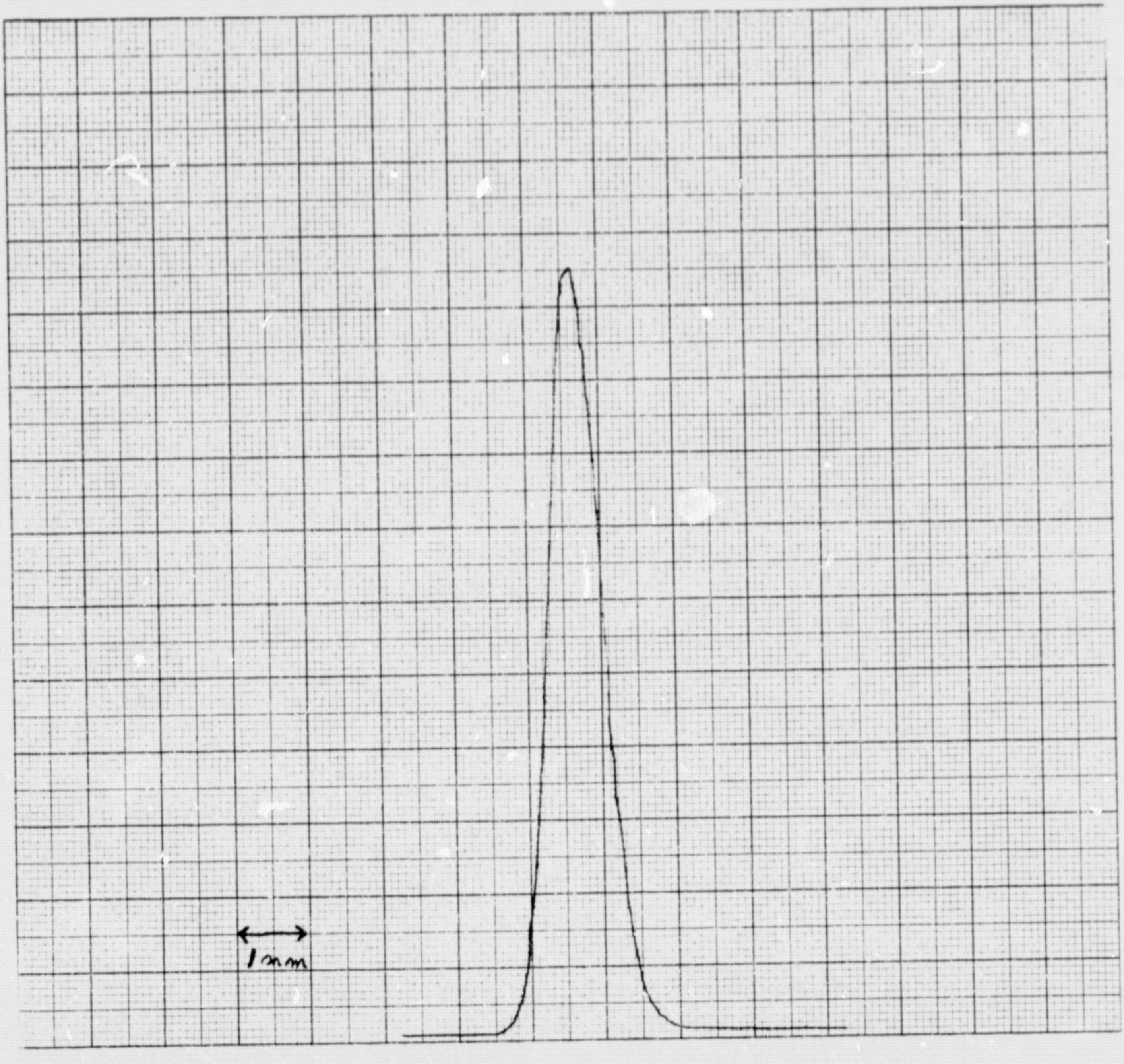


FIGURE 12 HORIZONTAL BEAM PROFILE
200 MHz Laser
1.064 μm

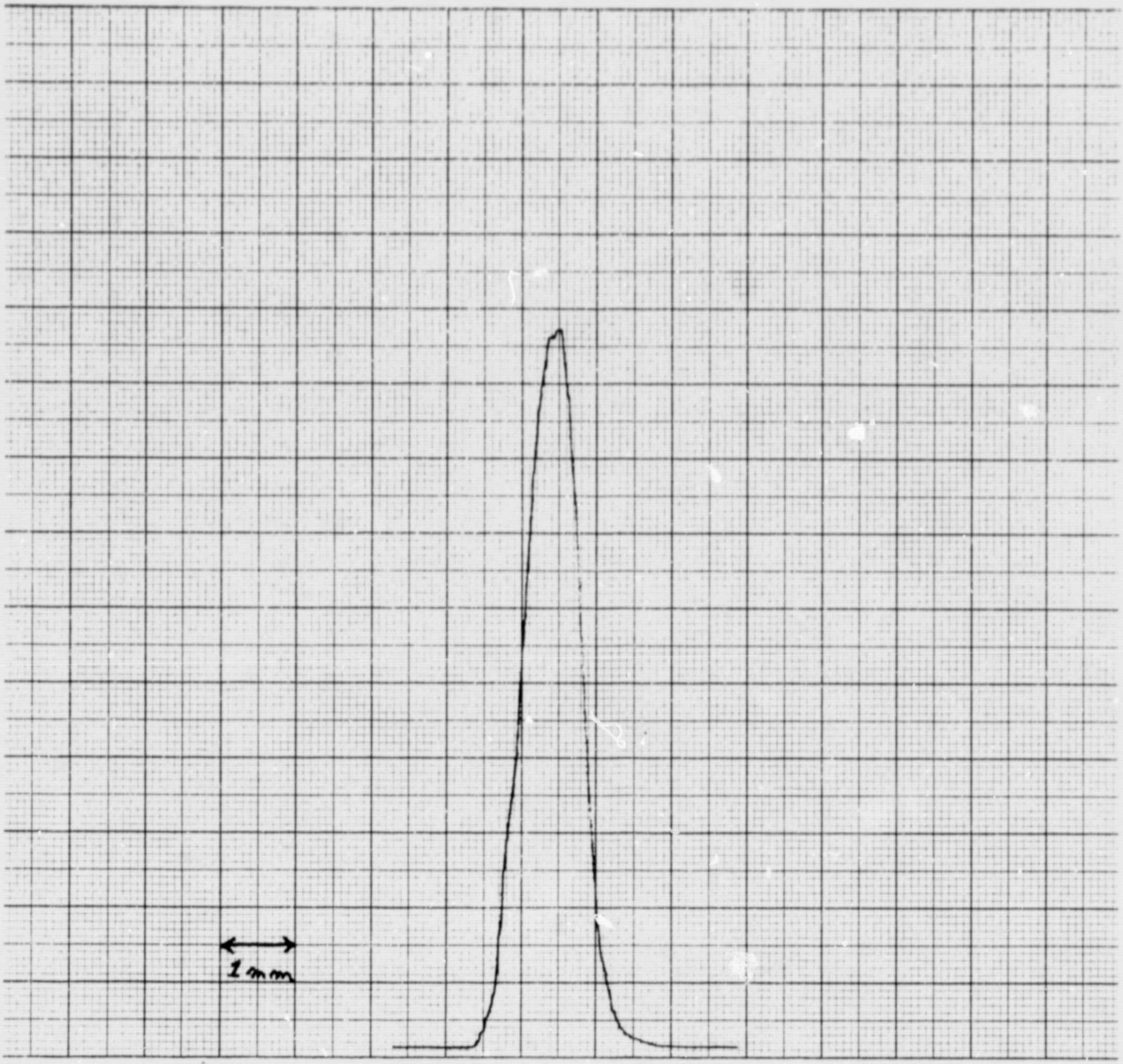


FIGURE 13 VERTICAL BEAM PROFILE
200 MHz Laser
1.064 μm

3.4 Mode Structure - Proper operation in the TEM_{00} mode and mode diameter was measured with a Gamma Scientific Scanning Photometer as shown in Figures 12 and 13. An intracavity aperture was used in the 400 Mpps laser to restrict operation to the TEM_{00} mode while the use of the curved end laser rod and collimated beam in the laser rod made the 200 Mpps laser self-aperturing in the proper mode.

4. OPERATION

To turn on the laser, it is only necessary to do the following three things. First, turn on the chilled water and adjust to 1.4 gallons per minute (GPM) flow rate. This rate provides the quietest operation of the laser. 1.0 GPM is the minimum flow rate required to remove the heat generated in the laser head and an upper limit of 1.6 GPM is recommended to maintain the internal pressure low enough that internal water leaks do not develop. Next, turn on the direct current power supply and adjust the lamp voltage to 90 volts. This is the desired operating point but voltages up to 110 volts may be used if more output power is required, although higher voltages will shorten pump lamp life appreciably. Finally, turn on the electronics power switch located on the relay rack chassis panel. This provides RF drive to the mode-locker and power for the temperature controllers and amplifiers used in the laser head. At the end of about 1/2 to 1 hour a slight adjustment in cavity length may be required to produce optimum pulse width. This is a function of the temperature of the laboratory, and once set it should remain fixed unless the temperature changes by more than 5°C (9°F).

To turn off the laser, switch off the electronics, reduce the lamp voltage to zero and turn off the chilled water supply. It is not necessary, or desirable, to leave the water flowing for more than one minute after the lamp power has been turned off as condensation inside the pump cavity may result.

5. ADJUSTMENTS

Minor adjustments to produce peak output power or best amplitude stability should be made at the flat (output) mirror. This results in little or no displacement of the optical beam in the laser rod and mode-locker. If both mirrors are adjusted, it may be necessary to make minor adjustments to the mode-locker for minimum pulse width.

If a complete realignment of the entire laser system is required, the use of a small (1 mW) Helium-Neon laser, operating in the visible portion of the spectrum, is recommended (Spectra Physics 132 or 133 or equivalent). Always introduce the beam into the laser through the flat (output) mirror. It is necessary to have the mode-locker in the cavity in approximately the correct position since it is a Brewester's angle device and causes considerable beam steering. The flat (output) mirror will reflect two spots since it has a

deliberate wedge built in to eliminate etalon effects. A drop of alcohol on the second surface will distort the reflection from that surface enabling one to determine the correct reflected spot to be used for alignment. The end of the laser rod also has a deliberate 1° tilt, for the reason cited above, and will not produce a reflection back at the alignment laser. The mode-locker will not reflect any light back either, since it is operated at Brewester's angle.

The first step in alignment is to center the alignment laser beam in the Nd:YAG laser rod. A clean beam must be seen at the output, free of rings or scattering from the rod holder. The mode-locker may now be adjusted so that the input and output beams are centered on the crystal faces. This will approximately establish the Brewester's angle condition and insure that the beam is passing through the acoustic column. The RF drive electronics may be turned on and the Bragg angle condition set approximately by observing the diffracted beam on a white card. This angle will be slightly different for 1.06 μm radiation than for 0.633 μm light, but will be close enough to cause mode-locking.

The final adjustments must be done with the laser operating at normal lamp input power and with the electronics turned on. The first step is to "walk" the beam around for maximum output power. This is also the point of quietest operation and best "feel" of the adjusting mirrors, i.e., a small movement of the mirror does not affect output power appreciably. The procedure used is to move the curved mirror a small amount in one direction then optimize output power by using both adjustments of the flat mirror. If the output power is higher than before, the alignment process is preceeding in the proper direction and another small change should be made in the same direction. Continue this process until the power reaches a peak, then proceed in the same manner with the other mirror adjustment.

The next adjustment sequence is to optimize the mode-locker. Make a very small change in the Brewester's angle adjustment, raise or lower the height adjustment to recenter the beam in the crystal, then optimize the output power by adjusting both micrometers on the mirror <u>nearest</u> the mode-locker. This is the flat (output) mirror on the 400 Mpps laser or the curved (high reflectivity) mirror on the 200 Mpps laser. Again, if output power increases the step was in the right direction and another step may be taken. This is a very broad range adjustment and power increases will be small. Changes of ±1° about the

optimum point do not affect operation or output power appreciably. The only reason for making very small changes each time is to avoid losing the laser due to beam steering.

The final adjustment is the Bragg angle tilt. This is best done by observing the output pulse on a sampling scope. A combination of angle adjustment and horizontal-vertical displacement to keep the beam centered in the acoustic column is necessary. Pulse width should be 200 ps $\pm$20 ps at the 10% amplitude points. If this can not be achieved, check the input RF level with a power meter. It should be between 700 to 1000 mW and appear "clean" when viewed on a fast real time scope.

A second cause for "fat pulses" could be that the mode-locker is not operating on a body resonance due to a change in the temperature controller or frequency drift of the master oscillator. Change the temperature of the mode-locker by 1°C and observe the pulse train. Do not go more than 10°C in either direction from the nominal operating point of 45°C to 48°C.

The nominal operating point for the external second harmonic generator is 88°C to 92°C and should be adjusted for maximum output power at 0.53 μm.